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Investigation of Nevşehir Perlite Aggregate in Terms of Alkali Silica Reaction

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Abstract

The alkali silica reaction (ASR) is a highly complex chemical reaction that adversely affects the durability of reinforced concrete elements today. Alkali silica gel is formed in the pores in the concrete when sufficient moisture is reached as a result of the combination of the alkalis in the cement and the amount of reactive silica in the aggregate. With this formation, alkali silica reaction begins. As a result of the water absorption of alkali silica gels, the internal stresses of the concrete increase and it causes damage by creating capillary cracks in the concrete. In this study, the effect of perlite aggregate obtained from Nevşehir region on alkali silica reaction was investigated. In this regard, accelerated mortar bar test (ASTM C 1260) method was carried out. Mixtures were prepared by replacing the crushed limestone aggregate with the perlite aggregate at 0, 10, 20, 30, 40, 50, 60 and 70 wt.% ratios. The length change values of these samples at 7, 14 and 28 days were measured. It was observed that the perlite aggregate substituted for the limestone aggregate in the mortar bars increased the alkali silica reaction.

Key Words
"Alkali silica reaction, perlite aggregate, accelerated mortar bar test method, The length changes"

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1. Introduction

Concrete, which is one of the most important factors keeping the structure alive in reinforced concrete structures, is a widely used building material. After the reinforced concrete structure is made, it must be protected against external factors. These external factors can be environmental factors such as climate changes, freeze-thaw effect, reinforcement corrosion and chemical factors such as alkali silica reaction and sulfate effect.

ASR starts when alkali oxides (Na_2O+0.658K_2O) in the cement and reactive silica (SiO_2) in the aggregate enter into a chemical reaction to form alkali silica gel with high water absorption capacity. Alkaline silica gels formed as a result of alkali silica reaction have high water absorption capacity. As a result of water absorption, it increases the internal stress of the concrete and causes damage by creating capillary cracks in the concrete (Demir et al. 2018; Demir et al. 2020; Pan et al. 2012; Thomas et al. 2006; Bazant &Steffens, 2000; Ramlochan et al. 2000). It is stated that substitution of reactive aggregates such as perlite, dazite, jibs, andesite, andesite tuff, which can be used as concrete aggregate, with aggregates such as limestone (non-reactive) in terms of alkali-silica reaction may also cause damage (Vivian, 1951; Gökçe & Şimsek, 2010).

There are many studies on the relationship between material design and ASR for concrete. In these studies, it was stated that protection can be provided from the damages caused by ASR with the use of mineral additives and the effects of low porosity w/c (water/cement) ratio (Esteves et al. 2012; Shehata & Thomas, 2002). There are several approaches to the prevention of ASR. Primarily, the removal of one or more of the factors causing the reaction such as moisture, reactive silica and alkali can be considered as a precaution. In addition, the damage of the reaction can be reduced by using mineral and chemical additives. These are materials such as lithium-based salts, silica fume as mineral additives, Blast furnace slag (BFS), Fly ash (FA) and rice husk ash (Massazza, 1993; Swamy, 1986; Bouzoubaâ et al. 2001; Demir & Sevim, 2017; Demir & Arslan, 2013; ASTM C618-19, 2019). Pozzolans, which are used as mineral additives, reduce the pH level by keeping the lime in the cement mortar. Lowering the pH value reduces the solubility of silica and prevents the formation of alkaline silica gel. There is always CaO in the gel structure. The absence of CaO indicates that the gel will not form. It can be said that pozzolans prevent gel formation by binding CaO (Thomas et al. 2011; Sata et al. 2007; Hasparyk et al. 2000; Ravina & Mehta, 1986; Saha et al. 2018).

In the study in which the pessimal reactive aggregate ratio of the Perlite Aggregate was examined by different methods, it was aimed to determine the reactive aggregate ratio, which gives the maximum length change of the perlite aggregate. For this purpose, the properties of Ankara Çubuk perlite aggregate in different proportions with Ankara Hasanoğlan limestone aggregate regarding alkali-silica reaction (ASR) are determined. It was determined according to ASTM C 1260 to determine the ASR on samples where perlite, limestone and both were used together. The mixtures were prepared by replacing the limestone aggregate with the perlite aggregate at the ratios of 0, 10, 20, 30, 40, 50 and 100 by weight. Samples containing 40% perlite aggregate underwent the highest change in length and were determined as the pessimal reactive aggregate ratio of perlite aggregate (Gökçe & Şimsek, 2010).

In this study, the effect of perlite aggregate (Nevşehir-Acıgöl) on alkali silica reaction was investigated. In this context, accelerated mortar bar test (ASTM C 1260) method tests were carried out. To form the mixtures, perlite aggregate was prepared by replacing 0, 10, 20, 30, 40, 50, 60 and 70 percent by weight of crushed limestone aggregate. The 7-, 14- and 28-days length change values of these samples were measured and compared.

2. Experimental Program

2.1. Materials

In this study, perlite aggregate was crushed and sized and grouped and taken from the plant in Nevşehir, Acıgöl. Crushed Limestone (CL) aggregate was obtained from Ankara Hasanoğlan region. Chemical and physical properties of aggregates and CEM I 42.5 R type Portland cement are given in Table 1.

Table 1. Physical and Chemical Properties of the Materials

Compound%	Perlite	Limestone	Cement
SiO_2	72.4	0.58	20.02
Al_2O_3	12.02	0.21	6.05
Fe_2O_3	0.77	0.48	2.94
CaO	0.39	57.4	60.41
MgO	0.18	0.84	2.12
SO_3	4.2	-	3.05
Na_2O	3.5	0.094	0.17
K_2O	3.2	0.032	0.61
TiO_2	0.01	0.01	-
MnO	0.007	0.009	-
Loss of Ignition	2.40	39.05	3.05
Total	98.06	98.69	98.52
Na_2O+0.658×K_2O			0.57

2.2. Methods
Experimental studies were performed according to the ASTM C 1260 Accelerated Mortar Bar Test Method (ASTM C1260-21, 2021). The experimental method used is summarized in Table 2.

Table 2. ASTM C 1260 test method

Method	ASTM C 1260
Sample	25×25×285 mm mortar bar
Water/cement ratio	0.47
Sand/cement ratio	2.25
Curing conditions	80°C 1 N NaOH solution
Test duration	14 days
Examination of the results	Detrimental zone>0.2% 0.2%>controlled zone>0.1% 0.1%>non-detrimental zone

ASTM C 1260 Accelerated mortar bar test method is a short-term test method that gives results in 16 days. The aggregate, prepared according to the gradation given in ASTM C 1260, was 2.25 times the cement amount and the water/cement ratio was 0.47, and 25×25×285 mm sized mortar bars were prepared (Table 3). After the prepared samples were poured into the molds, they were removed from the mold after being kept in the mold for 24 hours. The removed samples were kept in 1 N NaOH solution at 80 °C for 24 hours. After this period, the first reading of the samples was made and the 7-, 14- and 28-days length change values of the samples were read by keeping them in NaOH solution at 80 ºC, and the experiment was concluded (ASTM C1260-21, 2021). Aggregate mixture amounts of cementitious composite mortar bars are given Table 3. Here, CL stands for crushed limestone and NP represents total perlite ratio in aggregate mixture for gradation given in ASTM C 1260. Note that the following aggregate amounts have been corrected according to its water content and water absorption ratio.

Table 3. Aggregate mixture amounts of cementitious composite mortar bars (g)

Mixture	Sieve, mm									
	2.36-4.75 10%		1.18-2.36 25%		0.60-1.18 25%		0.30-0.60 25%		0.15-0.30 15%	
	Perlite	**CL**	**Perlite**	**CL**	**Perlite**	**CL**	**Perlite**	**CL**	**Perlite**	**CL**
NP 0	-	100	-	250	-	250	-	250	-	150
NP 10	9	90	22	225	22	225	22	225	13	135
NP 20	17	80	44	200	44	200	44	200	26	120
NP 30	26	70	65	175	65	175	65	175	39	105
NP 40	35	60	87	150	87	150	87	150	52	90
NP 50	44	50	107	125	107	125	107	125	66	75
NP 60	52	40	131	100	131	100	131	100	78	60
NP 70	61	30	153	75	153	75	153	75	92	45

Chemical analysis of perlite aggregate was carried out according to ASTM C 289 (ASTM C-289-07, 2007). For the chemical analysis method, the samples taken from the material remaining between 0.250 mm (No: 50) and 0.125 mm (No: 100) sieves of the perlite aggregate, whose reactivity will be determined, were washed under running distilled water to get rid of dust and fine particles, and the washed material was 105 ± It was dried in an oven at 5 ºC.

From the sieved, washed, and dried samples, 3 samples of 25 grams were taken with an electronic scale and put into the reaction vessel. 25 ml of 1 N NaOH solution was added to each of these vessels. 1 N NaOH solution was prepared by adding 40 g of sodium hydroxide to 900 ml of distilled water, and this solution was named sodium hydroxide solution. Only 25 ml of 1 N NaOH solution was placed in the fourth container without sample, and this container was used as a reference container.

Sample containers were placed in a constant water bath at 80 ± 1 ºC and kept for 24 hours. At the end of this period, the samples were removed from the water bath, cooled to 30 ºC, and filtered into a dry container by opening the lids. After mixing to ensure homogeneity, 10 ml was drawn with the help of a pipette and a 200 ml balloon was taken into a jug and made up to 200 ml with distilled water. This solution was used for the determination of dissolved silica and alkali reduction.

3. Results and Discussion

The results of the chemical analysis test and accelerated mortar bar, which were carried out to determine the alkali silica reaction in the samples obtained by substituting perlite aggregate (0, 10, 20, 30, 40, 50, 60 and 70%) from Nevşehir Acıgöl region and limestone aggregate obtained from Ankara Hasanoglan region, are evaluated below.

3.1. Alkali silica reactivity by chemical analysis method

The chemical analysis results of Alkali Silica Reactivity on perlite aggregate taken from Nevşehir region are given in Table 4.

Table 4. Chemical analysis results

Aggregate	Sc (millimole/liter)			Rc (millimole/liter)		
	Minimum	Maximum	Number of Samples	Minimum	Maximum	Number of Samples
Perlite (Nevşehir)	112	120	3	65	72	3

According to ASTM C-289 "Chemical Determination of Alkaline Silica Reactivity", the alkali reduction (Rc) and dissolved silica (Sc) values were determined with the help of the graphic in Figure 1, the location of the perlite aggregate. It is seen that the perlite aggregate obtained from the Nevşehir region is located in Region III, where it is defined as "Harmful aggregates" specified in the standards in terms of ASR.

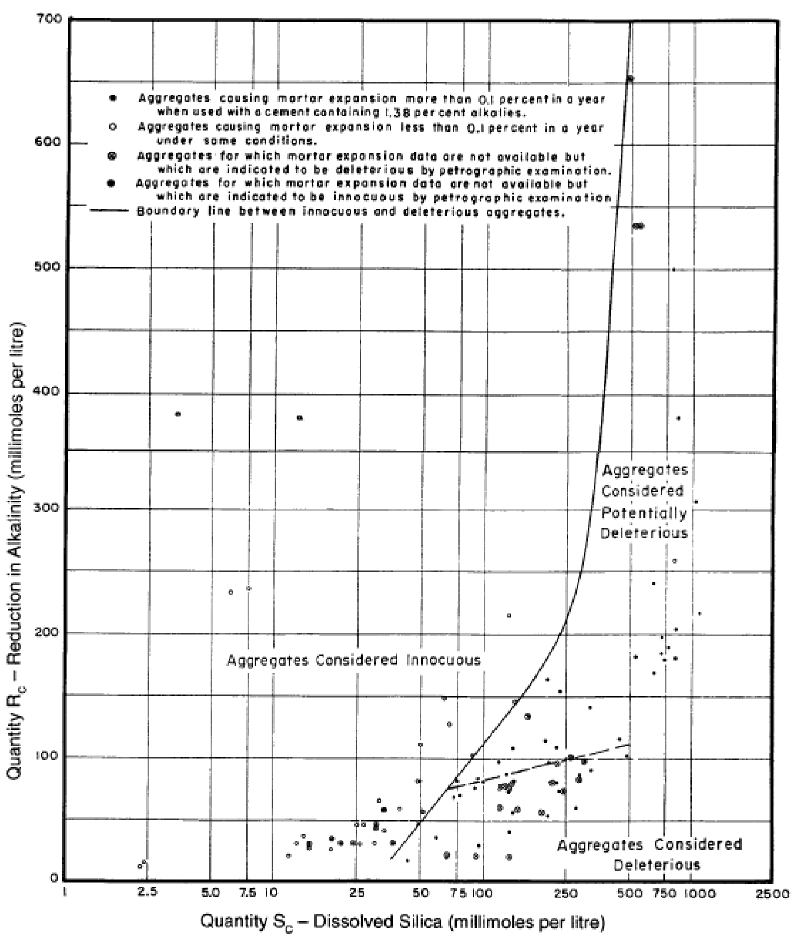

Figure 1. Classification of perlite aggregate using ASTM C 289 chart

3.2. ASTM C 1260 accelerated mortar bar test

In order to determine the ASR effect according to ASTM C 1260, which is the accelerated mortar bar test method, the 7- and 14-day length change (%) test results of the mortar sticks are given in comparison. The length changes obtained within the scope of the study are shown Figure 2.

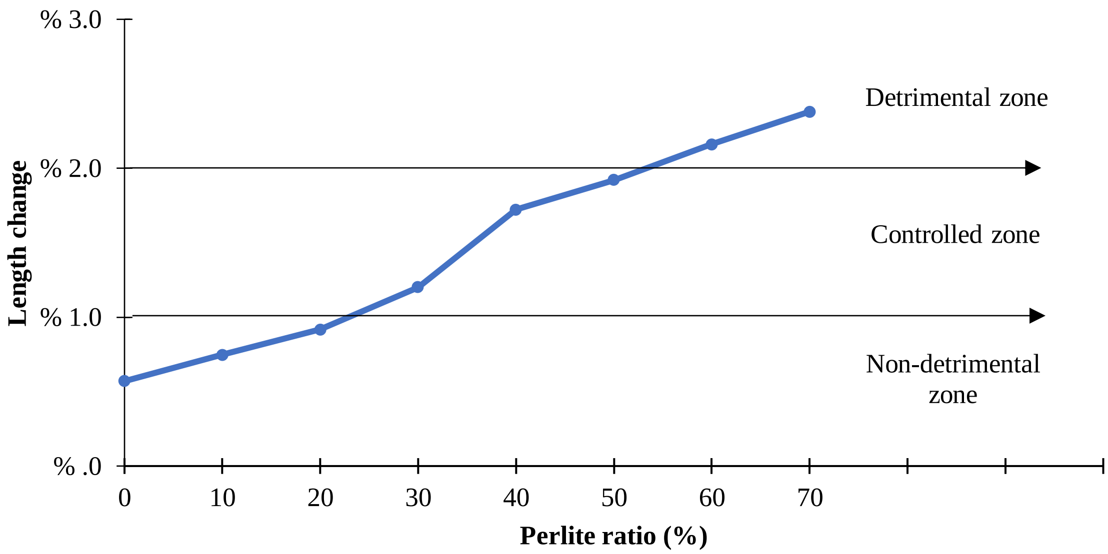

Figure 2. 7-day length change according to ASTM C 1260 of mortar bars with perlite aggregate additive

According to the values in Figure 2 and the interpretation made for 7-day length changes according to ASTM 1260; The lowest length change was observed in the NP0 mortar bar, which was produced entirely with limestone aggregate. The 7-day NP10 mortar bar ASR was found to be in the non-detrimental zone. On the other hand, NP20 was in the ASR non-detrimental zone according to the 7-day accelerated mortar bar. 7-day-old NP30, NP40 and NP50 mortar bars were found to be in the ASR controlled zone. 7-day NP60 and NP70 mortar bars were found to be in the detrimental zone in terms of ASR effect.

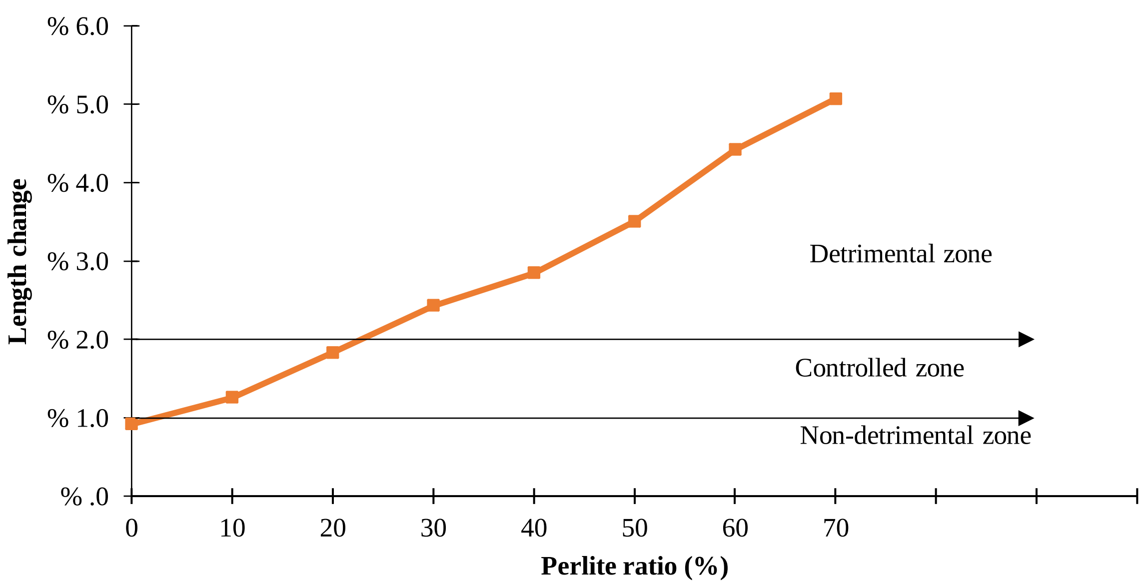

Figure 3. 14-day length change according to ASTM C 1260 of mortar bars with perlite aggregate additive

According to the values in Figure 3 and the interpretation made for 14-day length change according to ASTM 1260; The lowest length change ratio was observed in the NP0 mortar bar, which was produced entirely with limestone aggregate, which is called the control sample. As a result of the readings, the control samples (NP0) were qualified as harmless in terms of ASR according to ASTM C 1260. 14-day NP10 was found to be in the controlled zone (acceptable harmful zone) for ASR, and NP20 was also found to be in controlled zone for ASR. It was determined that the 14-day-old NP30, NP40, NP50, NP60 and NP70 mortar bar were in the detrimental zone in terms of ASR effect.

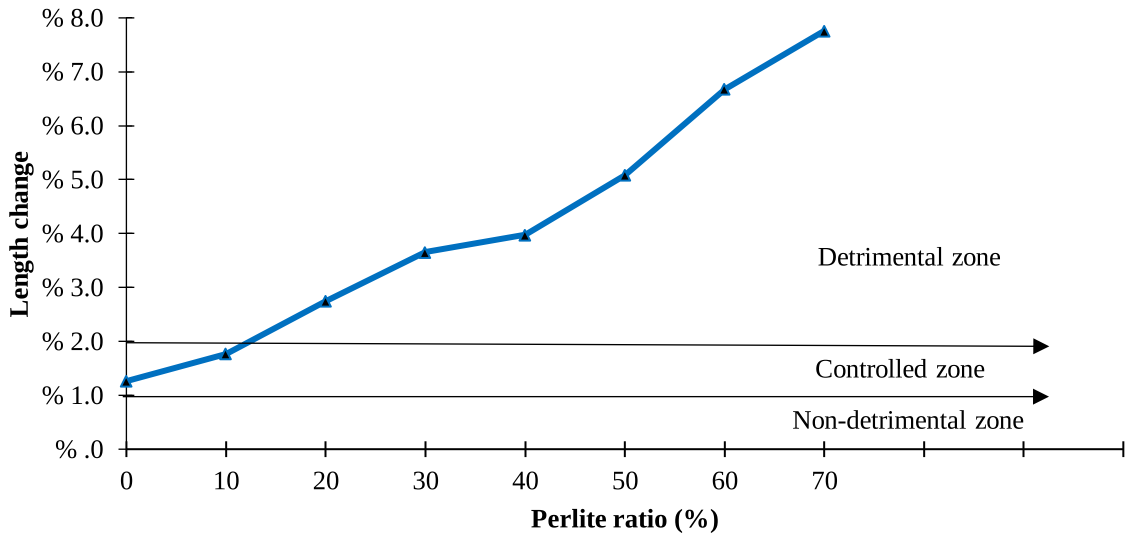

Figure 4. 28-day length change according to ASTM C 1260 of mortar bars with perlite aggregate additive

Although the experimental test method was 14 days old, in order to give an idea, an additional 28-day length change values were obtained. According to the values in Figure 4 and the interpretation made for daily length change according to ASTM 1260; As a result of the readings, it was seen that the control samples were in the acceptable harmful zone (controlled zone) in terms of 28-day NP10 ASR. Mortar bars NP20, NP30, NP40, NP50, NP60 and NP70 were found to be in the detrimental zone in terms of ASR effect.

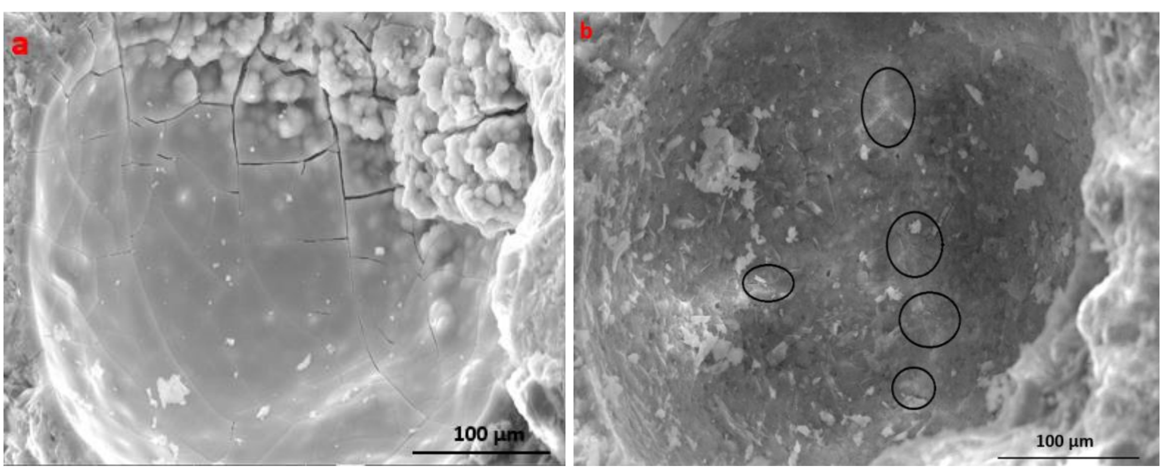

Figure 5. 1000× SEM image of the samples having 20% (a) and 0% (b) perlite replacement

Figure 5 (b) shows very small ASR cracks in the circled images, while large ASR expansions in the form of popcorn are seen next to very large ASR cracks in the samples replaced with 20% Perlite instead of aggregate. This shows that the ASR expansion is greater in the sample having perlite aggregates. The ASR was usually in the form of fractures and shrinkage cracks during the SEM study. Usually in a porous structure, cracks start and spread around the voids. The crack map in the SEM image and the gel reveals the presence of ASR. These voids are thought to be formed because of expansion of gel. The ASR products usually formed in and around aggregate cracks.

As a result, in this section, the lowest length change was observed in NP10 mortar bars produced entirely from limestone, while the highest length change was observed in NP70 perlite aggregate mortar bars replaced by 70% instead of limestone. In this case, the acceptable limit value of optimum perlite aggregate use for ASR was determined as 20% for 7 and 14 days, and 10% for 28 days.

4. Conclusion

In this study, the ASR effect that can be seen in the buildings was carried out to see the harmony of limestone and perlite aggregate. However, as the amount of perlite aggregate increased, the ASR effect increased. In the study, perlite aggregate was substituted for limestone aggregate at the rate of 10-70%. The results were discussed comparatively and ranked according to the findings obtained from the experimental studies,

- It has been observed that the perlite aggregate substitution made to the mortars produced with limestone increases the alkali silica reaction.
- According to ASTM C 1260; Perlite aggregate substitution up to 20% in 7- and 14-day mortar bars was found to be non-detrimental in terms of ASR.
- As a result of the experimental studies carried out according to ASTM C 1260, the greatest length change was observed in mortar bars with perlite aggregate substituted at the rate of 70%, while the lowest length change rate of 0% (mortar bars with limestone aggregate without perlite aggregate substituted) was obtained in mortar bars with perlite aggregate replacement.

As a result, it was observed that perlite substituted for the aggregate in the mortar bars increased the alkali silica reaction. In both chemical and rapid mortar bar method, perlite aggregate obtained from Nevşehir region is in the "harmful aggregate" class. This shows that two different experimental studies confirm each other. In the ASR effect, the optimum rate of perlite replacement for 7- and 14-days limestone was found to be 20%.

References

ASTM C1260-21. (2021) Standard test method for potential alkali reactivity of aggregates (Mortar-bar method), West Conshohocken, PA: ASTM International.

ASTM C289-07. (2007) Standard test method for potential alkali-silica reactivity of aggregates (chemical method), West Conshohocken, PA: ASTM International.

ASTM C618-19. (2019). Standard specification for coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete, West Conshohocken, PA: ASTM International.

Bažant, Z.P., & Steffens, A. (2000). Mathematical model for kinetics of alkali–silica reaction in concrete. Cement and concrete research, 30(3), 419-428.

Bouzoubaâ, N., Zhang, M.H., & Malhotra, V.M. (2001). Mechanical properties and durability of concrete made with high-volume fly ash blended cements using a coarse fly ash, Cement and Concrete Research, 31(10), 1393–1402.

Demir, İ., & Arslan, M. (2013). The mechanical and microstructural properties of Li2SO4, LiNO3, Li2CO3 and LiBr added mortars exposed to alkali-silica reaction, Construction and Building Materials, 42, 64–77.

Demir, İ., & Sevim, Ö. (2017) Effect of sulfate on cement mortars containing Li2SO4, LiNO3, Li2CO3 and LiBr, Construction and Building Materials, 156, 46–55.

Demir, İ., Sevim, Ö., & Kalkan, İ. (2018). Microstructural properties of lithium-added cement mortars subjected to alkali–silica reactions, Sadhana, 43(7), 1-10.

Demir, İ., Sivrikaya, B., Sevim, O., & Baran, M. (2020). A study on ASR mitigation by optimized particle size distribution. Construction and Building Materials, 261, 120492.

Esteves, T.C., Rajamma, R., Soares, D., Silva, A.S., Ferreira, V.M., & Labrincha, J.A. (2012). Use of biomass fly ash for mitigation of alkali-silica reaction of cement mortars, Construction and Building Materials, 26(1), 687–693.

Gökçe, H.S., & Şimşek, O. (2010). Perlit agregasının pesimum reaktif agrega oranının farklı yöntemlerle incelenmesi, Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 25(4), 839- 846.

Hasparyk, N.P., Monteiro, P.J., & Carasek, H. (2000). Effect of silica fume and rice husk ash on alkali-silica reaction, ACI Material Journal, 97(4), 486–492.

Massazza, F. (1993). Pozzolanic cements, Cement and Concrete Composites, 15(4), 185– 214.

Pan, J.W., Feng, Y.T., Wang, J.T., Sun, Q.C., Zhang, C.H., & Owen, D.R.J. (2012). Modeling of alkali-silica reaction in concrete: a review. Frontiers of Structural and Civil Engineering, 6(1), 1-18.

Ramlochan, T., Thomas, M., & Gruber, K.A. (2000). The effect of metakaolin on alkali–silica reaction in concrete. Cement and concrete research, 30(3), 339-344.

Ravina, D., & Mehta, P.K. (1986). Compressive strength of flow cement/high fly ash concrete, Cement and Concrete Research, 18, 571–583.

Saha, A.K., Khan, M.N.N., Sarker, P.K., Shaikh, F.A., & Pramanik, A. (2018). The ASR mechanism of reactive aggregates in concrete and its mitigation by fly ash: A critical review, Construction and Building Materials, 171, 743–758.

Sata, V. Jaturapitakkul, C., & Kiattikomol, K. (2007). Influence of pozzolan from various by-product materials on mechanical properties of high-strength concrete, Construction and Building Materials, 21(7), 1589–1598.

Shehata, M.H., & Thomas, M.D.A. (2002). Use of ternary blends containing silica fume and fly ash to suppress expansion due to alkali–silica reaction in concrete, Cement and Concrete Research, 32(3), 341–349.

Swamy, R.N. (1986). Cement Replacement Materials. London: Surrey University Press.

Thomas, M., Dunster, A., Nixon, P., & Blackwell, B. (2011). Effect of fly ash on the expansion of concrete due to alkali-silica reaction – exposure site studies, Cement and Concrete Composites, 33(3), 359–367.

Thomas, M., Fournier, B., Folliard, K., Ideker, J., & Shehata, M. (2006). Test methods for evaluating preventive measures for controlling expansion due to alkali–silica reaction in concrete. Cement and Concrete Research, 36(10), 1842-1856.

Vivian, H.E. (1951). Studies in Cement-Aggregate reaction, XIX: The Effect On Mortar Expansion of the Particle Size of the Reactive Component in the Aggregate, Australian Journal of Applied Science, 2, 108-113.